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A Cooperation Platform for Distributed Manufacturing

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Abstract. The aim of the paper is to analyse contemporary trends in distributed manufacturing (DM) research and to present a concept to develop and test some task allocation, planning and scheduling algorithms for DM network organisations. Some concepts are also adopted to identify key factor criteria and reasoning policies and rules for production/manufacturing decision support system. A final aim is to draw up a proposal for the development of a prototype decision support system with the necessary communication and knowledge-oriented modules to be implemented in an example of dynamic, DM and logistics network structure, particularly for very popular dynamic cluster forms in Poland. The developed concept of the organization of a multi-entity DM network will enable business-effective use of the system, supporting manufacturing decision-making, consulting and offering information services in the control centre (the so-called *Competence Centre*) by constructing virtual reality and access to services in a distributed network of cloud computing type. Integration of the whole system into one information system will enable further analysis and the network resource optimization of manufacturing and logistics processes, new analytical functions, reduction of delays in the manufacturing system, management of changes and risks, and visualization of the current state of the DM system.

Keywords: management, distributed manufacturing, resource allocation

Journal of Economic Literature codes: L23, M11, O14

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1. INTRODUCTION

The problem of distributed manufacturing (DM) or production cooperation management within dynamic network forms has recently been undertaken by a considerable number of research and industrial groups. For example, some results of DM projects have been described for cluster network systems (Akoorie & Ding, 2009; Liu *et al.*, 2017), additive manufacturing in car industry (Durão *et al.*, 2016), metal industry (Gąbka & Susz, 2016), administration in networked headquarters industrial environments (Moghaddam *et al.*, 2016), and sharing DM capacities in a *crowdsourced* way

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(Szaller *et al.*, 2020a; Szaller *et al.*, 2020b). Unfortunately, the research and implementation projects to be found in DM or distributed production (DP) management research bibliography and industrial reports basically do not have advanced (i.e. ready to use in practice) results – usually the final results are only pilot projects and experiments in planning and scheduling with an application of optimization, heuristic or evolutionary algorithms (also with simulation modelling and runs) for a particular cooperation system structure. The existing (so far) organizational and information-based solutions (or rather resolutions) in the described case studies of DM cooperation platforms in network (cluster) forms have a rather very limited range of functionalities.

The term DM refers to manufacturing systems (environments) consisting of a varying in time number of production organizations providing common access to a varying in time number of production resources and capacities in order to handle available production orders (e.g. production clusters, virtual and network production organizations). In such systems, a distributed production process of elements (e.g. modules) of the final product may be implemented, initiated by a negotiation process with the customer (having the characteristics of a classic batch production) or complete final products, created as a result of implementing a "glocal" strategy (achieving a "trade-up" effect – global effectiveness and adaptation to local requirements). In practical DM implementation, there is also an availability to apply many types of rather "classical" information and decision support systems (Rut, 2017a; Rut, 2017b), which are considered versatile systems. However, because of new business strategies and business models emerge, based particularly on collaborative or cooperation, Industry 4.0, IoT, and sustainable development paradigms with a "glocal" (global plus local) market focus, there is a strong need to develop new industrial systems – as a cooperation of dynamic network-oriented structures. And these structures need new communication, knowledge based, and decision-making support architectures to be extended.

Methodologies, architectures, environment and ICT for the "Industry 4.0" concept, which are developed and applied today to design, implement, and analyse manufacturing organizations are based on three types of integration: horizontal, vertical and digital e2e (Digital End-to-End) ones. Horizontal integration is the integration of various ICT systems used in various phases of business processes, including manufacturing processes in an organization (e.g. procurement logistics, production, distribution logistics, marketing) and/or in business-related organizations (e.g. value networks). Vertical integration, on the other hand, involves the integration of various ICT systems at different hierarchical levels of the organization (e.g. measurement and updating of data, manufacturing, production management, corporate planning) to obtain an e2e solution. The digital integration of e2e aims to integrate diverse ICT systems throughout engineering and management processes, meaning that digital (virtual) and real-world manufacturing worlds are integrated in the product/service value chain, while meeting the requirements of end-customers. Despite of many attempts to develop theoretical and implementation bases for the "Industry 4.0" concept, there are relatively few ideas to realise the intention of digital integration of e2e in DM, e.g. (Milisavljevic-Syed *et al.*, 2019; Zheng *et al.*, 2020).

The aim of the paper is to analyse contemporary trends in DM research and to present a concept to develop and test some business model frameworks and communication environments for DM decision support systems. A final aim is to draw up a proposal for the development of a prototype decision support system with the necessary communication and knowledge-oriented modules as a platform to be implemented in an example of dynamic, DM network structure, particularly for a very popular business cluster form in Poland. From the pragmatic point of view, the main purpose of the system prototype to be developed in the future, is to provide support for manufacturing clusters of small and medium size enterprises by setting information and communication environment to manage dynamic system cooperation. In the paper, the evolution of DM, case studies of emerging DM applications (e.g. Matt *et al.*, 2015; Srai *et al.*, 2016), and a description of a new DM paradigms and concepts for emerging modelling and information, communication technology (ICT) systems and other supporting improvements, are presented. Next, the economic, technological, societal and implementation issues that might limit the widespread adoption of DM, and future research agenda for the DM paradigm are described. The integration of all advisory functions, modelling, experiment execution and provision of training services in one information system will enable some important functionalities. For example, the proposed system will allow analysis and network optimization of manufacturing and logistics processes (e.g. production, supply, transport, storage, distribution), the addition of new analytical functions in the manufacturing network, using the synergy effect of many tools, reduction of delays between individual elements of the manufacturing system, management of changes and risks in the manufacturing system, and the visualization of the current state of the DM system or its selected elements.

2. DESIGN AND IMPLEMENTATION OF DM IN PRACTICE

This study focuses on DM in the present industrial context. A mixed (amalgam) methodology was employed, involving data input from production management journals and followed by a multiple case study method. The case study objectives were to investigate the scope, challenges and opportunities of specific DM innovations and to identify future research agendas. The initial stage consisted of a comparative study analysis of DM architectures, communications and information technologies applied in some practical implementations, modelling approaches to establish model repositories, methods of problem-solving in decision-making, types of cooperation business models and ranges of application systems' functionalities, and possible market demand fulfilment.

The case study of DM must be structured to capture the following issues: the description of the specific product and production technology system context, the characteristics of DM for a given technology production system, enabling production technologies and infrastructure, governance and regulatory issues to be addressed, sustainability considerations, and transformation challenges. The cooperation platform proposal for DM is based on some general approaches (e.g. systems approach, agent based technology, graph theory technology, BPM – business process management, and simulation modelling with GMB – group model building), and some methodological contributions to DM, e.g. internet-based technology (Woo *et al.*, 2008), cloud computing (Rauch *et al.*, 2016), business modelling (Seidenstricker *et al.*, 2017), heuristics for simultaneous balancing and scheduling jobs (Kays *et al.*, 2018), and smart contracts framework design (Dietrich *et al.*, 2020).

An important success factor in cooperative ventures is the proper selection of cooperation network participants. Manufacturing units assigned to specific tasks should meet a set of criteria, so that their contribution to the implementation of the contract can be integrated and can meet the requirements set by the final customer. As it turns out, a significant number of enterprises belonging to DM clusters or other networks forms, have the same or similar competences. It is therefore appropriate to develop mechanisms that will allow the identification of the best group of contractors for the contract/project in question. The selection of enterprises is usually based on an extensive set of criteria as variables in the mathematical models of the algorithms to be developed.

A typical manufacturing cluster is made up of many manufacturing companies which, on the one hand, cooperate with each other and, on the other, are in direct competition with each other. An important problem, therefore, is to match the right business model to such a situation, which on the one hand will enable each enterprise in the cluster to achieve added value in cooperation, and at the same time to maintain business identity and separation. An additional challenge is to increase the importance of additive manufacturing methods, which enables additional dispersion and, at the same time, reduction of the production system in a given company. Research and implementation work in the field of DM do not exceed pilot solutions and experiments of testing the application of optimization, evolution or heuristic algorithms (usually simulation with random searches) in production planning and scheduling. Existing ICT and organisational solutions and published descriptions of ICT platform examples for manufacturing organisation cooperation in the form of networks (including e.g. clusters) are usually limited in terms of the scope of their functionality.

A model example of cooperation development within a manufacturing network in the form of industrial clusters is the cooperation of companies in the Datang industrial district in the Chinese region of Zhejiang, creating a locally embedded local production system. The actors in the region rely on each other to invest in business, expecting others involved in the same game to shape and share a common framework. Companies voluntarily follow the rules, even if they do not like them. On the one hand, the cooperating firms want to be independent and to stay away from the constraints of the members of the network, but on the other hand, the networks also provide them with combined benefits and advantages which are sometimes impossible to achieve unless they are part of an internal circle. As a result, knowledge can be transferred between companies and the division of labour is more specialised.

Another interesting example of solutions for decision support systems for planning decisions of distributed production in a cluster is the production planning system used in China to cooperate in the cloud manufacturing of 10 automotive companies gathered in the Guangdong Zhaoqing Automotive Parts Industry Association. The manufacturing system consists of the following companies: Huaiji Dengyun Auto-parts (Holding) Co. Ltd. (Dengyun), Zhaoqing Honda Foundry Co. Ltd. (Honda), Guangdong Hongtu Technology (Holdings) Co. Ltd. (Hong Kong), Guangdong Sihui Shihui ShiLi Connecting-Rod Co. Ltd. (Shili), Guangdong Zhaoqing Power Foundry (Holding)

Co. Ltd. (Power), Guangdong Hong Teo Accurate Technology Co. Ltd. (Hong Teo), Delta Aluminium Industry Co. Ltd. (Delta), Zhaoqing Huafeng Electron Lvbo Co. Ltd. (Huafeng), Zhaoqing Sunspring Industrial Co. Ltd. (Sunspring), and Zhaoqing Fenghua Advanced Co. Ltd. (Fenghua).The basic function of the developed system in this implementation is to optimally determine the schedule for the performance of many manufacturing tasks in the cloud-based distributed manufacturing (CDM) system in order to achieve better performance of the entire cloud-based DM system. An important basis for scheduling tasks in CM is the task load. A proposal for a multi--tasking model for scheduling at CM was developed, including modelling of task load and other important service components (e.g. service efficiency index, service volume). The simulator developed by the company allows it to examine the influence of various scheduling methods on the system operation (e.g. on the total production time, service usage). The following scenarios are also considered: limitation/no time limit. The developed ICT system (model and simulator) and experimental system confirmed the following research hypotheses of cooperation within the framework of network cooperation: a) scheduling of tasks with a higher workload, but with a higher priority and no time limits, may shorten the make span and increase the use of service without reducing the quality of task execution, b) if there are time limits, the priority strategy allows one to perform a greater number of tasks and the quality of task execution does not decrease.

Another example of industrial research and development activities in DM is the prototype-laboratory model and environment for cooperation between a control centre (TUD – Darmstadt Polytechnic University, Germany) and a distributed production entity (USP – University of Sao Paulo, Brazil). The technical and organizational basis for business process management and scenarios of the proposed cooperation solution in a DM network is the conceptualisation and implementation of use cases for DM systems with additive (incremental) manufacturing (AM). The manufacturing context consisted of the product model developed for the company in Germany and the AM model for the production of spare parts for the company located in Brazil. In experimental studies, 4 models of use cases were implemented, confirming the possibility of the applied approach. TUD played the role of a central factory, USP played the role of a dispersed environment. 4 ways were simulated of performing production control in USP by TUD – from classical (order and lack of control) to production in USP with full control by TUD in a cyber-physical environment.

3. COOPERATION BENEFITS IN DM

The basic hypothesis of this paper is that the use of a properly constructed system of modelling and experimenting with the functionality of the cooperating DM network (as a communication platform) will enable achieving higher efficiency in the use of resources of the DM network participants, as well as acquiring knowledge and skills of DM system designers and enhancing cooperative managerial attitudes. The use of an integrated and intelligent communication platform together with a modelling, research experiment and decision support environment will also increase the interest of final product designers in new concepts and methods of DM management and technology (e.g. through the introduction of new AC technologies and 3D printing, participation in the process of product design), will enable verification of the DM knowledge and will trigger positive emotions related to group activities and the possibility of achieving success at various stages of system design.

To present the benefits of a cooperation strategy in a DM network, a simple System Dynamics (SD) simulation model has been developed to illustrate a cooperation game between network partners. To simplify our analysis, let us consider only a 3-manufacturer (M1, M2, M3) network system to implement no-cooperation (only individual) and coalition cooperation (e.g. M1 and M2) strategies in order to share limited production resources (L1, L2, L3) to fulfil customers' demands, i.e. orders (D1, D2, D3). The system's simple physical factors, like WIP (M1, M2, M3) levels, production supply flows (S1, S2, S3), final production flows (F1, F2, F3), and economic revenue (R1, R2, R3) are translated into stock and flow diagrams (Fig. 1, Fig. 2) with an application of the Vensim PLE software package to build the SD model and simulator of manufacturing processes and economic consequences of customer orders' processing. The development of a SD model includes usually several types of variables such as stocks, flows, auxiliary variables, lookup functions, constants and connectors. Stock, which is also known as level, acts as an accumulate (integration) reservoir of quantities (represented by rectangle) and describe the state variable of the system. The increasing flow (inflow) and decreasing flow (outflow) of a stock are also known as rates (represented by valve). The condition of the stock depends on the rates, while the rates can be influenced by the other factors affecting inflow or outflow which are known as converters or auxiliaries (sometimes represented by circle). Finally, the connector that represents cause and effect links within the model structure is represented by the single-line arrow. The basic paradigm of the SD method is that a system's behaviour depends on the underlying causal feedback structure, decision rules, amplifications and delays.

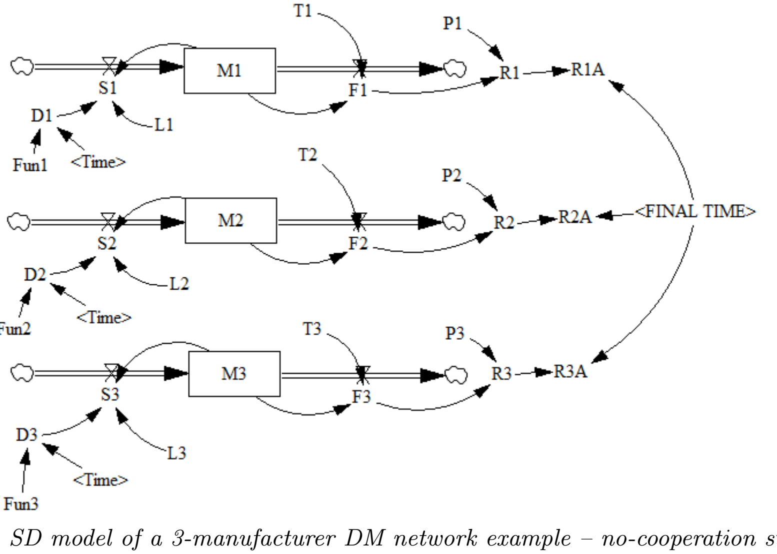

Fig. 1. *A SD model of a 3-manufacturer DM network example – no-cooperation strategy*

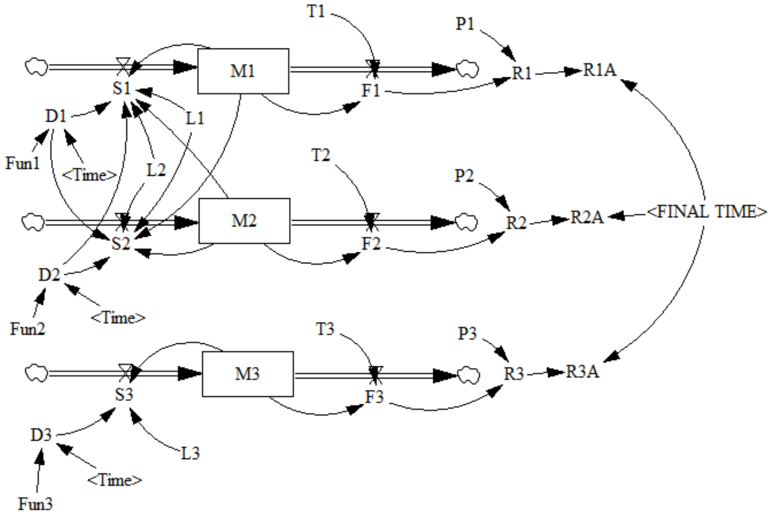

Fig. 2. *A SD model of a 3-manufacturer DM network example – M1 and M2 cooperation strategy*

After a model calibration stage to set input data for manufacturing times (T1, T2, T3) and final product prices (P1, P2, P3), a set of experiments is obviously to be run by introducing some changes in model parameters and customer orders' variability. But in the basic, only explanatory experiment example, we consider simple time dependent functions of customer orders (Fun1, Fun2, Fun3). Limits of manufacturing resources and customer orders (demand) are key factors for the effectiveness of the network cooperation strategies applied by participants.

A coalition of M1 and M2 manufacturers, as a simple form of network cooperation to be considered, allows us to increase the utilization of manufacturing resources (Fig. 3). The manufacturer M2 can take advantage of M1 manufacturer available (idle) resources. This result also confirms some simple cooperative game theory theses.

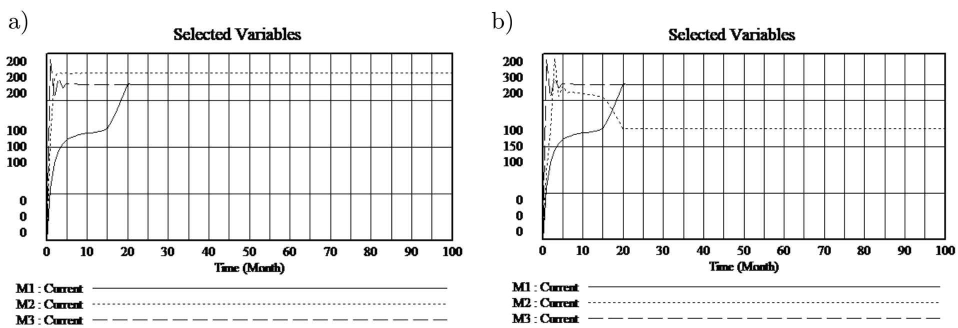

Fig. 3. *Dynamic SD model of a 3-manufacturer DM network example – simulation results of production levels in cooperation strategies: a) no-cooperation; b) coalition of M1 and M2*

Considering only manufacturers' average revenue (R1A, R2A, R3A) results, the first (rather empirical and simplified) experiment also proves the advantage of coalition cooperation strategy in comparison with a no-cooperation manufacturing strategy (Tab. 1) in manufacturing.

Table 1. *Input values, Models 1 and 2*

Cooperation strategy	**R1A**	**R2A**	**R3A**
No-cooperation	252.44	179.65	394.16
Cooperation M1+M2	252.44	185.54	394.16

4. COOPERATION PLATFORM ARCHITECTURE

The structure of any platform as an architecture (technologically integrated environment) for modelling, experimenting and supporting communication and decision-making, for the needs of increasing resource efficiency, is a result of specific industrial needs and the creativity of designers and organizations involved in the cooperation. However, still there is a lack of a coherent methodology (methodologies) for designing appropriate platforms for data modelling, model design and experimentation in the research process of new organisational solutions for industrial manufacturing structures. In particular, there is a need in the area of DM management to solve the economic and social problems of many domains (e.g. supply, planning of production/services, use of resources, maintaining stocks, transporting, distribution, environmental protection, sustainable development) and to obtain and use a wide variety of information – management of knowledge about economic systems and processes. For example, heuristics and optimisation models, which are used relatively often in manufacturing system models to solve decision-making problems in order to be applied effectively, require the collection, structuring, verification and updating of many relevant data, contained in databases or domain repositories. Data included in transactional, planning, decision-making and execution ICT systems of the following types: ERP (Enterprise Resource Planning), MES (Manufacturing Execution Systems), APS (Advanced Planning and Scheduling), EAM (Enterprise Assets Management) and BI (Business Intelligence) are not always useful in solving problems of production management practice.

The proposed solution to the problem of cooperation between DM systems is the use of Cloud Manufacturing (CM), Holonic Control (HC) and Multi-Agent Based (MAB) approaches in system architecture design. The basic information domains (holons) of the production sphere necessary in the design and construction of the modelling and decision support platform include:

- products/services, final customers and markets;
- executive structure of production/services (orders, processes, resources, costs);
- suppliers of products/services (location, costs and restrictions, risk of cooperation);
- external and internal transport network (structure, costs, capacity, modal capacity, transport constraints);

– finance, accounting and reporting (accounting and cost recording, price setting, revenue, profit and value of the organization, measurement of effects in the supply chain);
– strategy and tactics of the organization (mission, action plan, nature of cooperation with partners, development policy, business models);
– demand forecasting (statistical and forecasting methods, time series with information on the history of the system);
– economic and macroeconomic environment (competitiveness on the market, availability of resources, economic situation, possibilities of internationalisation of activity);
– data on business performance is made available to decision-makers (scope, structure, sensitivity of data, form of data, possibilities of generating scenarios).

The proposed concept of an information system architecture with its implementation environment in limited and variable availability of resources involves the development of an ICT platform using a dynamic data and knowledge repository. The platform is based on graph ontology, reference business processes and decision-making events occurring in network manufacturing activity (production or service delivery) and related logistics activities. The information system must have the features of an integrated service-oriented system, organizing work and optimizing the distribution of tasks in the execution of production/service orders for cooperating participants of the production network (Fig. 4). The main features of the proposed architecture are new rules and algorithms identification for production decision-making (planning, scheduling and resource allocation) in the management of network structures. Particularly, the architecture consists of a production cluster with a coordination centre, a data mining system to create a database repository based on the graph model, a new service of centralized production planning based on shared production resources using a set of heuristic models, optimization and simulation of the network of cooperating production and logistics companies, CM Internet platform for the exchange of production information in the production network, and new design and training services in planning and implementation of network production with shared production resources based on Group Model Building (GMB) sessions.

The manufacturing logistics processes still requiring innovative improvements are: documenting and ordering procedures, planning and supply management, machine and equipment operation logistics, information flow (information management), cooperation with suppliers and customers, internal cooperation between functional departments, and R&D centres, cash flow logistics.

A problem of particular importance which has not yet been solved in the Polish economic reality, particularly in industrial cluster forms of cooperation, is the role of the cluster coordinator (animator), what kind of competences it should have, and what kind of relations with the environment it should build. This problem is one of the key issues within some discussions on cluster structure management. The institution of a cluster coordinator (cluster initiative) in the Polish economic reality is a matter of a permanent (so far) searching for answers, e.g. which model of coordinator activity would be optimal in the Polish conditions. The models used in other countries should not be transferred without reflection to the Polish economy without taking into account its specific nature.

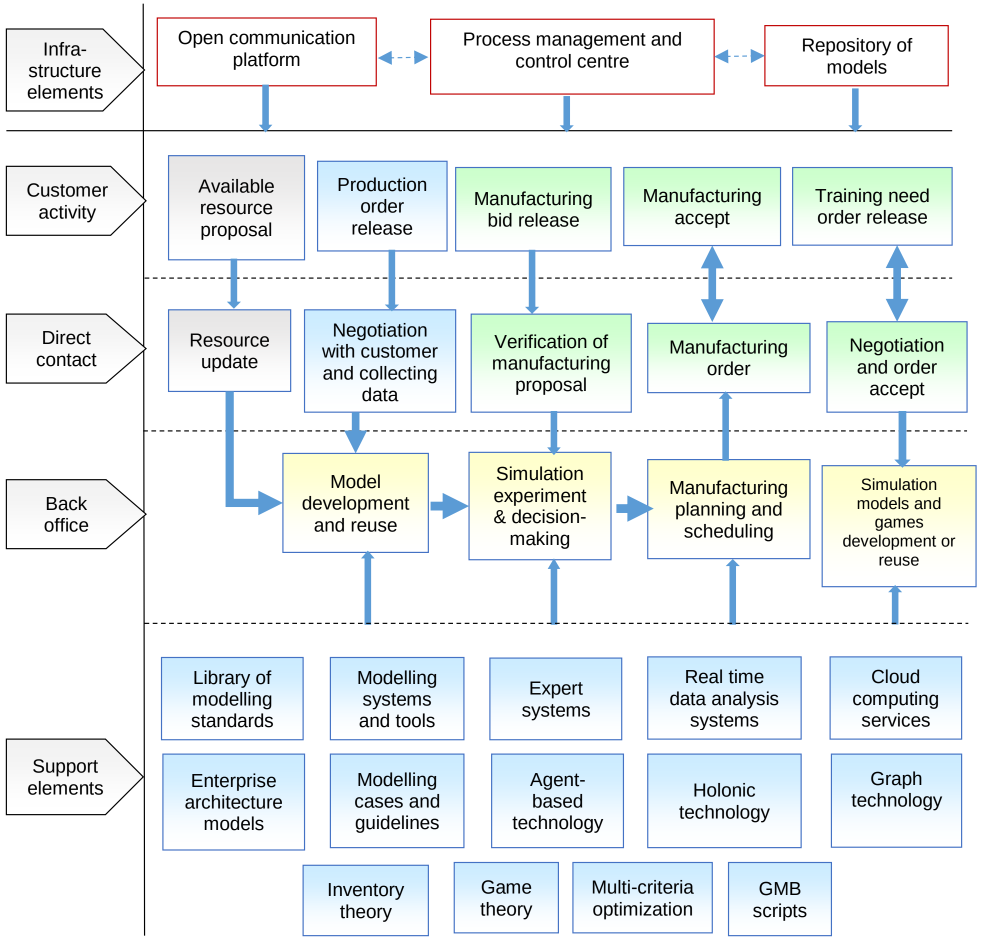

Fig. 4. *Service Blueprint business process diagram of the cooperation concept in a DM network*

The studies and works described in the literature on DM management indicate the need for a holistic approach to the integration of models and algorithms of planning and optimization. This concerns in particular methods of model decomposition and optimization problems into sub-problems and their integration into a model and algorithm composed of models and algorithms for solving the identified sub-problems, which are tailored to the specific problems under consideration (and therefore these methods are not universal), and also designing a universal strategy for the construction of hybrid algorithms, which are limited to the integration of different algorithms into a hybrid algorithm to solve the whole problem, and not only its sub-problems. Similar concepts and proposed pilot structures described in the literature of DM do not exceed the state of basic research and experiments on the proposed optimization, heuristic or simulation models.

Some similar DM research results, which aimed to find a universal ICT tool partially comparative to the undertaken concept, indicate numerous limitations, rather weak relevance, and the incompleteness of methods developed so far to be applied in a network integration for a dynamic DM environment. Particularly, these refer to: manufacturing system architectures, description of business manufacturing processes and provided services, and their translation (automatic) into the manufacturing phase, quality and business capabilities of manufacturing processes, automation of composition of manufacturing tasks and provided services, data flow management and control, and the ability to adapt and integrate systems.

Basic research needs to select an appropriate DM network architecture are related to the problem of service composition, as the process of building and then controlling the implementation of complex schemes for the execution of manufacturing tasks and services. Extensible Markup Language (XML), as recommended by the World Wide Web Consortium (www.w3c.com), such as WSDL (Web Services Description Language) or OWL-S (Web Ontology Language for the Semantic Web), is usually used to describe business manufacturing processes. Domain ontologies are also used as dictionaries, allowing the description of the functionality and interfaces of services. These languages are not dedicated to the representation of business processes and ownership of the executive service environment and non-functional service parameters. On the other hand, quality assurance and business process capability tasks in manufacturing networks are usually solved partially, for selected parameters, thus the proposed architecture should expand the subject matter and develop new methods of process feasibility analysis and assessment.

The proposed concept of an information and organisational platform to support the DM network will also affect the implementation of the sustainable development principle in the following ways:

- By the use of DM potentials, instead of investing in a new equipment, technological lines or departments, individual companies will also consider the possibility of using the potentials of other companies and the use of a cooperation platform. Abandoned unnecessary investments will not burden the environment during equipment manufacturing/installation time and also during the equipment operational use;
- Taking into account the location of the final destination due to the production order, by optimisation of logistics process algorithms implemented in the decision support system, it will be possible to reduce the total demand for transportation activities. Therefore, the DM system will reduce negative impact of transportation on the environment, and it will also reduce manufacturing and delivery lead times;
- By the use of the DM platform, there will be a better use of manufacturing potentials, individual companies will improve the utilisation and efficiency of the resources and production lines;

– The use of the cooperation platform via the "*Communication and Negotiation Portal*" for work organisation will reduce the amount of office work needed to be done in comparison to a classic organisation. The vast majority of communication processes, negotiations, work organization and supervision during manufacturing order processing will be based on communication and documentation in electronic/digital form.

Most of the production network organizations in Poland are made up of small and medium size enterprises, which are in direct competition with other companies in a given structure. The most common form of cooperation in a manufacturing (production) network organisation in Poland is that of a cluster. However, the greatest barrier to cluster development in Poland is still a low openness to cooperation between enterprises and coordination entities. It is caused partly by the inheritance left by a centrally planned economy, the relatively short period of development of the private enterprise sector and the dominance of misunderstood competition culture, which does not see opportunities for joint development in cooperation in selected areas of activity. This is due to the low level of trust between economic partners as well as ordinary citizens, as evidenced by various studies, including the European Social Survey (ESS). In clusters there are companies that simultaneously cooperate and compete with each other, which makes it difficult to find a cluster management strategy that everyone accepts, and even more difficult to find a suitable tool to support the management of such organisation. Additionally, the majority of companies in production or logistics clusters in Poland are micro, small and medium size enterprises.

The cluster research surveys for Polish organizations clearly indicate the need to find a solution based on a DM or network systems in the area of common product/service management. As an example, a part of the nationwide cluster benchmarking carried out in 2010, 47 selected clusters from among 178 network organisations (clusters and cluster initiatives) were studied. In the area of cluster infrastructure research, it was stated that "*the use of a common internal network in Polish clusters is small*", only in 12 clusters members use the internal network, half of which is actively used by fewer than 50% of members. In the remaining five clusters almost all entities use information from the Intranet network (76–100%), but only in one cluster is the Intranet used by 51–75% of its members. It should be noted, however, that clusters that do not use Intranet tools often use tools that deliver similar functions (e.g. in the form of joint websites). Even joint marketing activities are aimed at promoting the cluster rather than directly improving the situation of its members. Therefore, the low performance in improving competitiveness is a result of small number of initiatives taken in this area and attracting new members to a cluster is rather limited. Also, the rather low degree of openness to cluster cooperation is caused by the low expected benefits of current and potential cluster members. The declared benefits relate more to cooperation or human resources development than to the improvement of the company's performance. In this situation, the sustainability of at least some cluster structures may be at risk.

The basic functions of a tool supporting the DM system and environment management are focused on the "added value principle" – the DM network generates added value in the form of products and services that cannot be provided by one company in a given quantity, time and quality. The most common need is to work together in order to achieve economies of scale and mutual benefits from common manufacturing resources. This means that the most important objectives of the management system are the assessment of the customer's order, the selection of appropriate manufacturing resources and the control of their availability in time, as well as the joint management of the production order execution. The above functions, due to the very nature of the network organisation, must be adapted to operate in conditions of dynamic change to the organisation's structure during the planning and execution of the order.

A problem of particular importance is the role of the cluster coordinator (animator) and what kind of competences it should have and what kind of relations with the environment it should build. It should be noted that the institution of a cluster coordinator (cluster initiative) is a matter of permanent (so far) searching for answers as to which model of coordinator activity would be optimal in Polish conditions. Coordinators, apart from their strictly animation function, should undertake a number of direct actions for entities operating in the cluster, e.g. consulting, training, technology transfer, expansion into foreign markets, promotion. A coordinator may also act as a leader in joint projects of several cluster entities, e.g. related to the construction of a laboratory or a promotional campaign for a cluster. It can also act as an intermediary in relations with external contractors and negotiate, for example, better conditions for the supply of goods and services on behalf of its members. Appropriate cooperation of enterprises and cluster coordinator with business environment institutions is important, as they often have resources and competences unavailable for individual enterprises or coordinator and which they would have to gain only afterwards. Examples include: appropriate laboratory facilities, premises infrastructure, which can be made available e.g. by technological parks or various types of advisory competences available to regional development agencies, technology transfer centres and consulting entities.

It is therefore necessary to develop properly functioning relations between cluster members, business environment institutions, and the coordinator, because without these relations the cluster as a structure in practice does not exist. An answer to the need to find a solution in the area of common product/service management for Polish organizations based on a DM system is to develop such a system of distributed resources management, that would allow to assess the potential of an external customer order, select appropriate production resources from the ones provided by the members of the organization, and then manage the execution of the production order in such a way, that it does not differ from the standards presented by leading single large production companies.

An appropriate data repository (information database, database of models, database of processes, database of knowledge) would contain the necessary information on the companies, partners cooperating with them, products/services and many other data enabling to design scenarios for already existing and exploited models of manufacturing organizations, e.g. models and production management simulation games, transport-delivery-logistics (TSL) models, as well as to design new models mapping these areas of activity. This will also provide an opportunity to show the participants of the manufacturing process (decision makers, employees, trainees, students) realistic problem situations (resulting from the educational context), in which they have to make a decision on an action in a specific situation. The construction of a data repository dedicated to such needs would also enable the design of new versions of simulation models and the organization of training sessions with an appropriate discussion of decision-making cases and their consequences.

An organization equipped with a proposed multi-criteria decision support system will be able to conduct a transparent decision-making procedure concerning its implementation, when receiving an order together with the client's requirements. In the first phase, in the context of the criteria, the best technology is to be identified and alternatives ranked in order of their suitability for the requirements. In this way, the system not only systematizes and makes the decision-making process transparent, but also adds flexibility, because in the case of not finding the right production unit with the technology selected first, it is possible to quickly replace a production variant and at the same time swiftly compare the solutions according to defined criteria. The second phase – consisting in the selection of contractors – can then be effectively implemented and, in the event of unforeseen events, modified on the basis of the logic of the supporting system, which creates a unique comfort for decision-makers, who are usually forced to rely on intuition in business personal relationships in "emergency" situations.

5. COOPERATION PLATFORM DESIGN STAGES – A PROPOSAL

One of the important functions of DM management is making decisions in situations of solving complex, usually unstructured problems, with the participation of many participants - actors (including agents with different goals). This requires the creation of appropriate forms of production situations' description – acquiring and structuring knowledge about production systems, its modelling, making available and effective use in economic practice. The basic problems of using e2e digital approach in designing and functioning of integrated and effective manufacturing organizations include:

- developing an appropriate overall architecture for managing the communication processes of cooperation between independent production network partners;
- implementation of a common methodology for value analysis, calculation of achieved results and analysis of organisational effectiveness;
- developing an integrated and flexible organisation of the production system based on a well-designed platform for information exchange, modelling and experimentation.

However, the existing management systems do not fulfil their purposes under conditions of continuous changeability of production resources (both in terms of quantity and type/structure attributes). To a certain extent, the new direction of development of management systems – "*Digital Factory*" – responds to this demand but focuses mainly on the integration of multiple systems by introducing appropriate interfaces for data exchange. Modern business models move towards ill-defined and dynamic networks of cooperating manufacturing organisations such as production clusters and/or more closely related network/virtual organisations. Hence there is a need to develop new business models and accompanying management systems supporting the above-mentioned organizations.

The DM cooperation platform concept described in the paper is just in a form of an early stage research proposal, currently being verified in terms of methodological and technological requirements, and the chances of attracting interest in a pilot DM network (e.g. manufacturing cluster). This chapter proposes a DM framework design to increase the transparency and auditability of manufacturing capacities and resources in collaborative manufacturing DM networks by adopting the auction and contracting approach supported by open-access ICT technology. The proposed design of the DM system architecture should integrate the following functions:

– selection of contractors for production tasks, taking into account technology preferences and other criteria (e.g. time, cost, quality, risk);
– selection of appropriate manufacturing technology, taking into account the criteria predefined by the contracting authority technologies will be considered in two main groups: conventional processing, and additive manufacturing (AM);
– selection and reservation of contractors' resources of for the needs of orders;
– maintaining the current network model of the manufacturing environment during the planning and execution of the orders;
– maintaining and updating the production plan for cooperation environment;
– simulation of the manufacturing process for different product variants, contractors, technologies and production resources with variable availability of resources.

The proposed detailed procedure for the pilot system development (design, prototype construction and implementation) of a cooperation platform, by defining the information technology and communication environment with the production system modelling subsystem and its information environment, aims to achieve particularly the following main three objectives: the development of design assumptions to model integration and cooperation of DM systems (Tab. 2), the design of heuristics, simulation and optimization models to develop a reference DM system model of cooperating enterprises (Tab. 3), and DM cooperation platform prototype development with business processes' infrastructure (orchestration and choreography models), manufacturing network and control centre establishment (Tab. 4).

Table 2. *Objective I stages in the proposed procedure to develop a pilot DM system*

Objective I	Development stages
Development of design assumptions to model integration and cooperation of DM systems	– definition of functions and technical characteristics of cooperating manufacturing systems, determination of the scope of cooperation and development of a set of problem situations to be reflected in the integrated model of cooperation (system context, modelling objective, model type, frame and mode of the experiment, type of model users, type of recipients of the results of the experiment); – formulating a conceptual domain model (system structure, decision-making rules, system behaviour, transformations) and defining the application case (type of business, decision-making scope, system participants);

Table 2. cont.

Objective I	**Development stages**
Development of design assumptions to model integration and cooperation of DM systems	– development of a methodology for the integration of internal systems supporting production and production management of cooperating production systems and defining the principles and methods of data structuring (data sources, data availability, data selection methods); – setting the input and output data for the model (manufacturing data from repositories, identification of the information types on manufacturing system behaviour, and decision variables); – definition, development, updating and maintenance of input and output data models reflecting the economic reality of companies providing their production and service resources for the needs of organised activities within a cluster/corporation using data and simulation modelling systems; – development and implementation of a communication interface (user interface) between the control system and all relevant, application-oriented information systems, used in cooperating companies (central database and distributed database systems) based on previous research analyses

Table 3. *Objective II stages in the proposed procedure to develop a pilot DM system*

Objective II	**Development stages**
Design of heuristics, simulation and optimization models to develop a reference DM system model of cooperating industrial enterprises	– designing a database necessary to build a simulator and the experimental environment, including the definition of structures (objects, attributes, relationships), and other information used in the integrated reference, object-oriented simulation model with graph theory method support; – development of a database by simulation experiments (object-oriented ERM data modelling) and a knowledge database on problem situations, methods of solving problems occurring in the cooperating manufacturing network; – building a knowledge management system for knowledge generated during a simulation experiment (documents, history of system states, images, etc.); – construction, testing, verification and validation of the simulator (executive model generating the reaction of the manufacturing system model to the introduced variants of the model input data scenarios); – design and implementation of simulation experiments (designing the scenario and the initial situation of the model, designing changes in the structure of the model, designing data visualization modules); – developing a methodology to identify problems and problem situations in the area of production and logistics management and developing procedure scripts for the organization of Group Model Building (GMB) method interventions and training sessions in cooperating companies

Table 4. *Objective II stages in the proposed procedure to develop a pilot DM system*

Objective III	Development stages
DM cooperation platform prototype development with business processes' infrastructure (orchestration and choreography models), manufacturing systems network and control centre establishment	– definition and construction of the infrastructure for the communication system with partners in the prototype DM network, and the methodology of using the developed system in making or supporting production decisions (planning, optimization, simulation, decision-making); – definition and development of BPM models describing the activities of customers – participants of the DM network; – definition and development of BPM models of services and direct contacts with customers – participants of the DM network; – definition and development of BPM models for the description of system back office activities (modelling, optimization, planning, consulting and training) in cooperation with the participants of the DM network prototype; – determination and selection of supporting elements for the system background (modelling, optimization, planning, consulting and training) in cooperation with the participants of the DM network prototype; – preparation of a training programme for DM network participants

6. CONCLUSIONS

In order to achieve a better position on the market, modern industrial enterprises establish cooperation between themselves, creating manufacturing networks, clusters, and other structures based on cooperative business models. In this way, they develop and strengthen their potential, because (as a group) they have a chance to increase capacities of manufacturing, capital and human resources. The DM network, supported by multi-criteria decision support system with communication and knowledge modules, can select the best, optimal technology due to resource utilisation, and also a hierarchy of alternatives to satisfy customer requirements. The overall system not only allows the systematic structuring of technologies, but also the transparency of the decision-making process with flexibility – in the case of manufacturing deadlocks, or a lack of sufficient resources. It is possible to recommend an alternative technology with some manufacturing simulation tests in a wide range of criteria.

The goal of the proposed architecture is also to test some tasks allocations, planning and scheduling algorithms, to identify key factor criteria and reasoning rules for a production decision support system, and finally to develop a decision support system with the necessary communication and knowledge-oriented modules to be implemented in dynamic DM cluster forms. The results of the paper are: the synthetic review and classification of DM strategies, forms and a concept for collaborative DM platform to be developed. The concept is an architecture and prototype platform development process for manufacturing decision support and communication in DM environment with communication by SOA service-oriented support, and modelling activities with knowledge-oriented modules. It tends towards a support to not only management in network-oriented organisations as clusters or centres of excellence, but also towards a support to production managers. By means of the complex simulations and multi-factor analysis suggested in the research project, it would be possible to determine efficiency and effectiveness of resource and task or work allocation within manufacturing shop floor or line structures, modifications in product design and technology selection. It will allow the better organisation and reduction of planning and manufacturing cycle times in cooperative, network model of manufacturing, also an integration of manufacturing network organisation with 5PL partners who deliver logistics services, and finally an increase of effectiveness and competitiveness of network (e.g. cluster) by an increase of capacity use.

The proposed information system, as well as the supporting implementation environment of simulation models with the use of decision-making algorithms in the area of DM management, will also enable (at least) the solution of the basic methodological problems in modelling, research and implementation of networked production/manufacturing and logistics structures. Particularly, by means of the application of the DM platform, some important DM research and practical issues can be undertaken, e.g. structured ontology design, data meta-modelling, experimental scenario design, structure functionality and effectiveness evaluation, business model, business strategy and production policy design, sustainable development strategy implementation requirements, delays, capacity constraints, service levels, production/manufacturing and logistics cost, demand volatility impacts on the network functioning in terms of effectiveness, efficiency, and optimality.

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